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(71) **Applicant: KOREA BASIC SCIENCE INSTITUTE** [KR/KR]; 52, Eoeun-dong, Yusung-gu, Daejeon 305-333 (KR).

(72) **Inventors: CHOI, Yeon Suk;** #903-605, Yeolmaemaeul 9-danji Apt., 521, Noeun-dong, Yuseong-gu, Daejeon 305-768 (KR). **KIM, Dong Lak;** #10-1202, Garam Apt., Dunsan 3-dong, Seo-gu, Daejeon 302-744 (KR). **KIM, Myung Su;** #204-1501, Galma Apt., Galma-dong, Seo-gu, Daejeon 302-755 (KR).

(74) **Agent: KIM, Sun-young;** Korea Coal Center, 10th Floor, 80-6, Susong-Dong, Chongro-Ku, Seoul 110-727 (KR).

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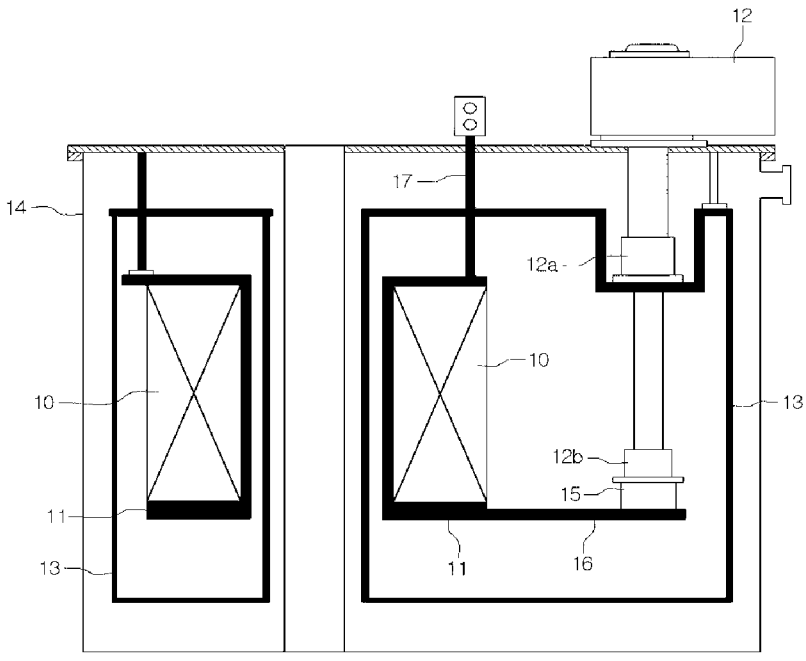
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**(54) Title:** COOLING SYSTEM FOR SUPERCONDUCTIVE MAGNETS




**(57) Abstract:** A cooling system for superconductive magnets according to the present disclosure includes a vacuous container, a superconductive magnet forming a magnetic field, a superconductive magnet bobbin surrounding the superconductive magnet and made of thermally conductive material, a freezer for exchanging heat with the superconductive magnet bobbin to cool the superconductive magnet, a vibration-type heat pipe contacting the superconductive magnet bobbin to induce heat exchange with the freezer, and a radiation shield for blocking heat radiation introduced to the superconductive magnet. Therefore, it is possible to implement a stable cyrogenie cooling system, which may eliminate the generation of a temperature gradient between the freezer and the superconductive magnet so that the superconductive magnet may be efficiently cooled and may recover a superconducting status within a short time.

# Description

## Title of Invention: COOLING SYSTEM FOR SUPER¬ CONDUCTIVE MAGNETS

### Technical Field

[1] This disclosure relates to a cooling system for superconductive magnets, and more particularly, to a cyrogenic cooling system for superconductive magnets, which decrease a temperature gradient between a freezer and a superconductive magnet to zero by using a vibration-type heat pipe to maximize cooling efficiency of the superconductive magnet.

### Background Art

[2] Superconducting phenomenon represents that a material abruptly loses electric resistance at a certain temperature and flows electricity without any restriction. There is a material which loses electric resistance and flows electricity without any restriction when being cooled to 0 degree in absolute temperature (-273 C), which is called a superconductor. The superconductor exhibits its property when being cooled to an extremely low temperature below a critical temperature. Niobium titanium (NbTi) and niobium tin ($Nb_3$ Sn)havingasuperconductingcharacteristicnearaliquidheliumtemperature(-268 C at 1 atm) are called a Low Temperature Superconductor (LST), and BSCCO-based materials having a superconducting characteristic near a liquid nitrogen temperature (-196 C at 1 atm) are called a High Temperature Superconductor (HTS). Material such as YBCO shows a superconducting characteristic between two temperatures.

[3] Recently, a conductive cooling method for cooling by means of thermal conductive characteristics of a metal by using a small cyrogenic freezer as a heat sink has been used in order to cool a superconductive magnet using a superconducting material. However, the cyrogenic freezer has deteriorated performance in a magnetic field generated by the superconductive magnet and thus should be spaced apart from the superconductive magnet by a predetermined distance. Therefore, a temperature gradient is generated along a cooling medium between the cyrogenic freezer and the superconductive magnet, which reduces the cooling efficiency.

### Disclosure of Invention

### Technical Problem

[4] This disclosure is directed to providing a cyrogenic cooling system for superconductive magnets, which include a vibration-type heat pipe exchanging heat between a superconductive magnet and a freezer to effectively cool a superconductive magnet to an extremely low temperature so that a temperature gradient between the freezer and

the superconductive magnet decreases to zero.

## Solution to Problem

[5] In one general aspect, there is provided a cooling system for superconductive magnets, which includes: a vacuous container; a superconductive magnet forming a magnetic field; a superconductive magnet bobbin surrounding the superconductive magnet and made of thermally conductive material; a freezer for exchanging heat with the superconductive magnet bobbin to cool the superconductive magnet; a vibration-type heat pipe contacting the superconductive magnet bobbin to induce heat exchange with the freezer; and a radiation shield for blocking heat radiation introduced to the superconductive magnet.

[6] The freezer may include a first-stage freezing unit and a second-stage freezing unit, the first-stage freezing unit may be thermally connected to the radiation shield to minimize radiant heat introduced to the superconductive magnet from the outside, and the second-stage freezing unit may be thermally connected to the vibration-type heat pipe to extract heat from the vibration-type heat pipe.

[7] The vibration-type heat pipe may include a working fluid therein, the working fluid may liquefy by means of fluid cooling of the second-stage freezing unit in a condensation unit thermally connected to the second-stage freezing unit, the working fluid may evaporate by means of heat generated at the superconductive magnet in an evaporation unit thermally connected to the superconductive magnet bobbin, and heat may be extracted from the superconductive magnet to cool the superconductive magnet.

[8] The vibration-type heat pipe may repeat evaporation and condensation of the working fluid as the working fluid circulates therein, which extracts heat generated from the superconductive magnet to cool the superconductive magnet.

[9] The freezer and the superconductive magnet may be connected by means of the vibration-type heat pipe to eliminate the generation of a temperature gradient.

[10] The working fluid may include at least one of helium, hydrogen, neon, nitrogen and their mixtures.

## Advantageous Effects of Invention

[11] According to the present disclosure, by providing a vibration-type heat pipe between a first-stage freezing unit and a second-stage freezing unit of a freezer and a superconductive magnet, it is possible to eliminate the generation of a temperature gradient between the freezer and the superconductive magnet and thus efficiently cool the superconductive magnet.

[12] In addition, by using the vibration-type heat pipe, it is possible to implement a stable cyrogenic cooling system which may absorb an abundant amount of heat energy

generated at the superconductive magnet by using latent heat of the working fluid in the superconductive magnet and transfer the heat energy to the freezer to recover a superconducting status within a short time.

[13] The number and size of freezers may be selected by determining a cooling capacity depending on the size of the superconductive magnet, namely the amount of heat generation, and the number of vibration-type heat pipes may also be determined accordingly. Therefore, it is possible to efficiently cool the superconductive magnet.

## Brief Description of Drawings

[14] The above and other aspects, features and advantages of the disclosed exemplary embodiments will be more apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[15] Fig. 1 is a schematic view showing a cooling system for superconductive magnets according to the present disclosure; and

[16] Fig. 2 is a schematic view showing a vibration-type heat pipe according to the present disclosure.

## Mode for the Invention

[17] Hereinafter, a configuration of a cooling system for superconductive magnets according to the present disclosure will be described in detail with reference to the accompanying drawings. Fig. 1 is a schematic view showing a cooling system for superconductive magnets according to the present disclosure. Referring to Fig. 1, the cooling system for superconductive magnets includes a vacuous container 14, a superconductive magnet 10, a superconductive magnet bobbin 11, a freezer 12, a vibration-type heat pipe 16, and a radiation shield 13. The vacuous container 14 maintains the inside of the cooling system for superconductive magnets in a vacuous status. The superconductive magnet 10 forms a magnetic field, and the superconductive magnet bobbin 11 surrounds the superconductive magnet 10 and is made of thermally conductive material. The freezer 12 exchanges heat with the superconductive magnet bobbin 11 and cools the superconductive magnet 10. The vibration-type heat pipe 16 contacts the superconductive magnet bobbin 11 to induce heat exchange with the freezer 12. The radiation shield 13 blocks heat radiation introduced to the superconductive magnet 10.

[18] The superconductive magnet 10 is surrounded by the superconductive magnet bobbin 11 fabricated by winding a superconductive wire, and electric current is supplied to the superconductive magnet bobbin 11 through a current leading wire 17 from the outside of a vacuous container 14 so that the superconductive magnet 10 may generate a magnetic field. The superconductive magnet bobbin 11 contacts one end of the vibration-type heat pipe 16. In addition, the other end of the vibration-type heat pipe 16

contacts the freezer 12. The freezer 12 has a two-stage cooling structure including a first-stage freezing unit 12a and a second-stage freezing unit 12b. A cooling capacity is supplied from a main body of the freezer 12 provided out of the vacuous container 14, and the first-stage freezing unit 12a contacts the radiation shield 13 at its outside and cools radiant heat introduced to the superconductive magnet 10. The second-stage freezing unit 12b contacts a thermal link 15, and the thermal link 15 contacts one end of the vibration-type heat pipe 16. The thermal link 15 exchanges heat between the second-stage freezing unit 12b and one end of the vibration-type heat pipe 16. In other words, the first-stage freezing unit 12a is thermally connected to the radiation shield 13 to minimize radiant heat introduced to the superconductive magnet 10 from the outside, and the second-stage freezing unit 12b is thermally connected to the vibration-type heat pipe 16 to extract heat from the vibration-type heat pipe 16 so that the superconductive magnet 10 may be cooled to an extremely low temperature.

[19] Fig. 2 is a schematic view showing a vibration-type heat pipe according to the present disclosure. Referring to Fig. 2, the vibration-type heat pipe 16 may include a condensation unit (a heat absorption unit) 19 and an evaporation unit (a heat emitting unit) 18. The vibration-type heat pipe 16 includes a pipe 20 extending and repeatedly bending between the condensation unit 19 and the evaporation unit 18.

[20] The extending pipe 20 contains a working fluid which may be cooled to an extremely low temperature. The condensation unit 19 is connected to the thermal link 15 and is thermally connected to the second-stage freezing unit 12b of the freezer 12. The working fluid is condensed by means of the cooling capacity of the second-stage freezing unit 12b. The evaporation unit 18 contacts the superconductive magnet bobbin 11 surrounding the superconductive magnet 10. The heat generated at the superconductive magnet 10 may be transferred to the evaporation unit 18 of the vibration-type heat pipe 16 through the superconductive magnet bobbin 11 to cool the superconductive magnet 10.

[21] In an initial stage, the pipe 20 is filled with a working fluid in a gas state through a cyrogenic valve 21 provided at one end of the pipe 20 of the vibration-type heat pipe 16. After that, the freezer 12 is operated so that the working fluid liquefies, and the liquefied working fluid initially cools the superconductive magnet 10. Once being supplied, the working fluid circulates in the pipe 20 to reciprocate between the condensation unit 19 and the evaporation unit 18, and so it is not needed to additionally supply a working fluid afterwards.

[22] The working fluid may be selected as desired according to the operating condition of the superconductive magnet 10. The working fluid may use any one of helium (He), hydrogen ($H_2$),neon(Ne) ,andnitrogen($N_2$),whichmayalsobeusedinmixture. The operating temperature may range from 3K to 10K in case of using helium as the

working fluid circulating in the pipe 20, the operating temperature may range from 17K to 26K in case of using hydrogen, the operating temperature may range from 27K to 34K in case of using neon, and the operating temperature may range from 65K to 90K in case of using nitrogen. Since the working fluid may be selected as desired according to the operating condition of the superconductive magnet 10, the heat transfer efficiency may be maximized in a wide temperature range.

[23] In addition, the vibration-type heat pipe 16 of the present disclosure may have a small design regardless of the distance to a subject to be cooled, namely the superconductive magnet 10, and may also cool a subject far away from the freezer 12 without a temperature gradient. If the superconducting characteristic is lost (namely, quench) while the cooling system for superconductive magnets is in operation, since the working fluid is present in the vibration-type heat pipe 16 of the present disclosure, an abundant amount of heat energy generated at the superconductive magnet 10 may be absorbed by using latent heat of the working fluid, and the energy may be transferred to the freezer 12 to recover a superconducting status within a short time. Therefore, the present disclosure may be regarded as a very stable cyrogenic cooling system.

[24] As shown in Fig. 2, two or more vibration-type heat pipes 16 may be provided, and the number and size of freezers 12 may also be selected according to the size of the superconductive magnet 10, namely the amount of heat generation. Accordingly, the number of vibration-type heat pipes 16 is determined. Therefore, it is possible to ensure optimized cyrogenic cooling.

[25] By using the cooling system for superconductive magnets as described above, it is possible to implement a stable cyrogenic cooling system which may eliminate the generation of a temperature gradient between the freezer and the superconductive magnet so that the superconductive magnet may be efficiently cooled and to recover a superconducting status within a short time.

[26] While the exemplary embodiments have been shown and described, it will be understood by those skilled in the art that various changes in form and details may be made thereto without departing from the spirit and scope of this disclosure as defined by the appended claims.

## Industrial Applicability

[27] by providing a vibration-type heat pipe between a first-stage freezing unit and a second-stage freezing unit of a freezer and a superconductive magnet, it is possible to eliminate the generation of a temperature gradient between the freezer and the superconductive magnet and thus efficiently cool the superconductive magnet.

# Claims

[Claim 1] A cooling system for superconductive magnets, comprising:
a vacuous container;
a superconductive magnet forming a magnetic field;
a superconductive magnet bobbin surrounding the superconductive magnet and made of thermally conductive material;
a freezer for exchanging heat with the superconductive magnet bobbin to cool the superconductive magnet;
a vibration-type heat pipe contacting the superconductive magnet bobbin to induce heat exchange with the freezer; and
a radiation shield for blocking heat radiation introduced to the superconductive magnet.

[Claim 2] The cooling system for superconductive magnets according to claim 1, wherein the freezer includes a first-stage freezing unit and a second-stage freezing unit,
wherein the first-stage freezing unit is thermally connected to the radiation shield to minimize radiant heat introduced to the superconductive magnet from the outside, and
wherein the second-stage freezing unit is thermally connected to the vibration-type heat pipe to extract heat from the vibration-type heat pipe.

[Claim 3] The cooling system for superconductive magnets according to claim 2, wherein the vibration-type heat pipe includes a working fluid therein,
wherein the working fluid liquefies by means of fluid cooling of the second-stage freezing unit in a condensation unit thermally connected to the second-stage freezing unit,
wherein the working fluid evaporates by means of heat generated at the superconductive magnet in an evaporation unit thermally connected to the superconductive magnet bobbin, and
wherein heat is extracted from the superconductive magnet to cool the superconductive magnet.

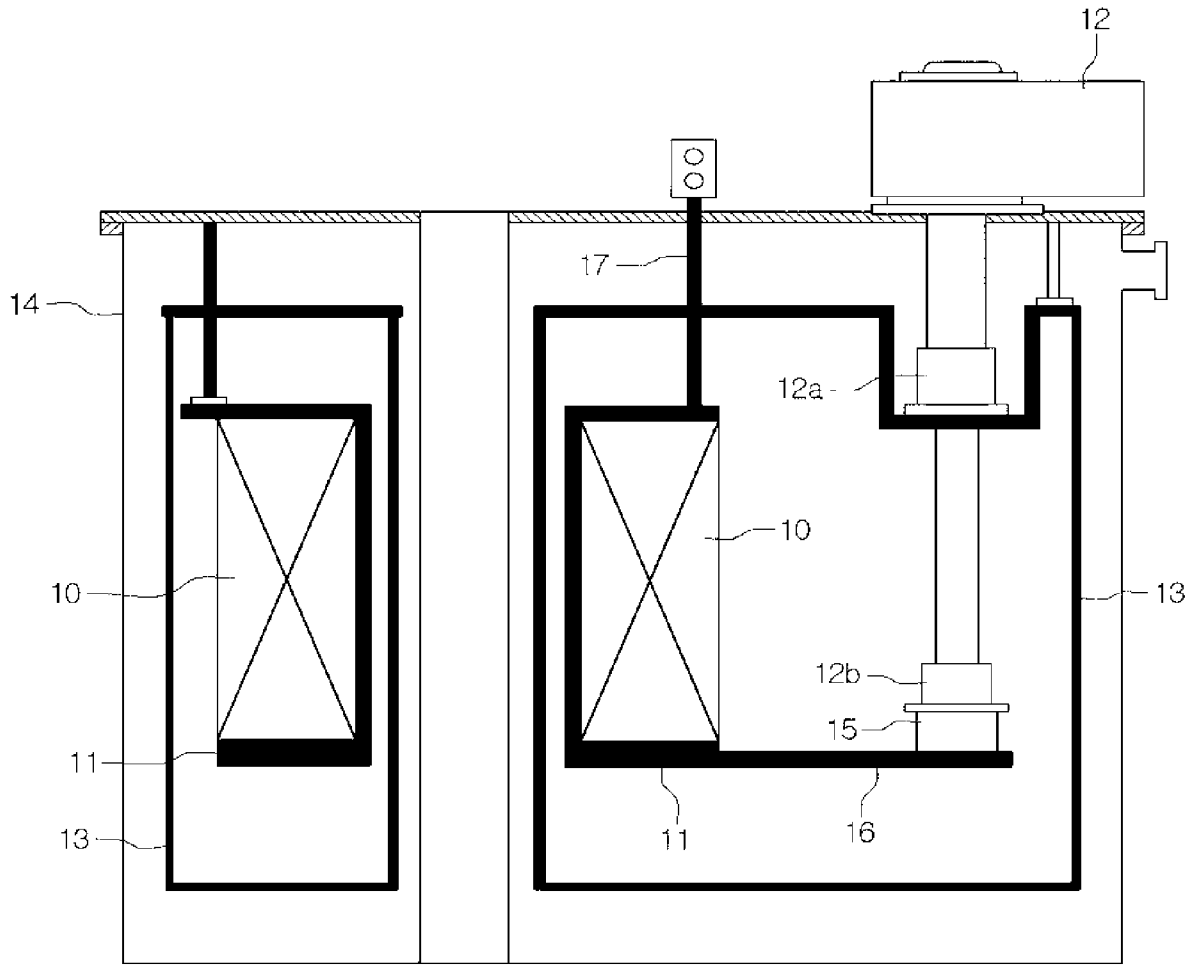
[Claim 4] The cooling system for superconductive magnets according to claim 3, wherein the vibration-type heat pipe repeats evaporation and condensation of the working fluid as the working fluid circulates therein, which extracts heat generated from the superconductive magnet to cool the superconductive magnet.

[Claim 5] The cooling system for superconductive magnets according to claim 4,

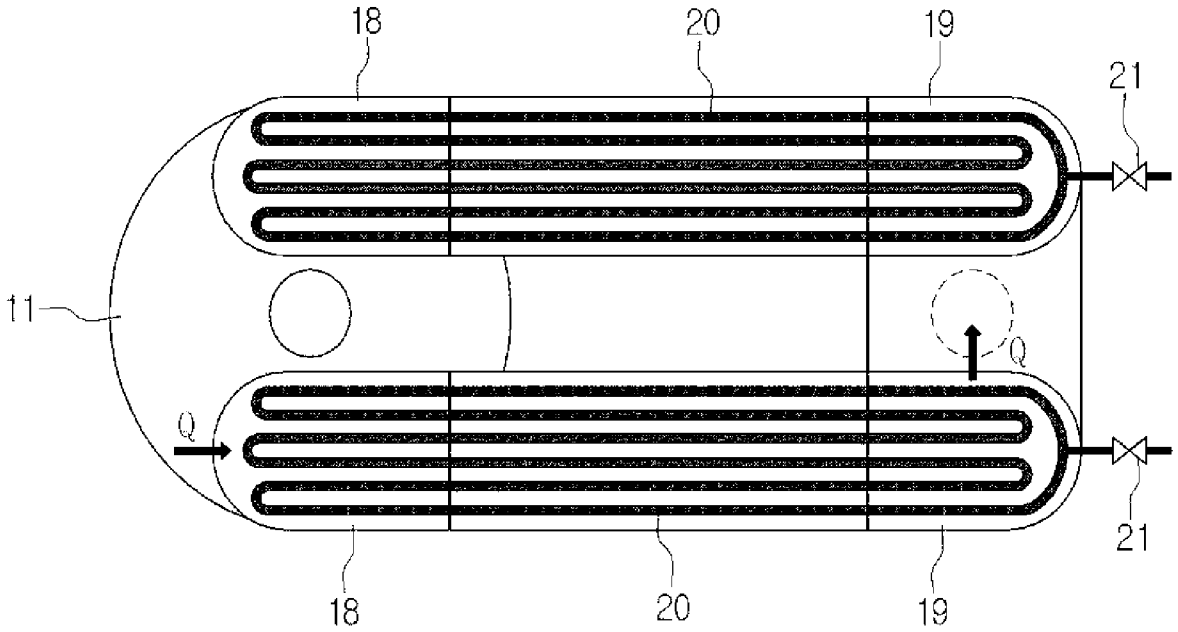
wherein the freezer and the superconductive magnet are connected by means of the vibration-type heat pipe to eliminate the generation of a temperature gradient.

[Claim 6] The cooling system for superconductive magnets according to claim 3, wherein the working fluid includes at least one of helium, hydrogen, neon, nitrogen and their mixtures.

[Fig. 1]




[Fig. 2]



**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/KR2012/009912**

**A. CLASSIFICATION OF SUBJECT MATTER**

***HOIF 6/04(2006.01)i***

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

HOIF 6/04; HOIL 39/24; F25B 19/00; F25D 3/10; G01R 33/035; F25B 9/00; H01L 39/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: superconductive magnets, cooling system, heat exchanger, working fluid

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | JP 2009-243837 A (TOSHIBA CORP.) 22 October 2009<br>See paragraphs [0020]-[0025] and figure 1. | 1-6 |
| Y | US 2010-0248968 Al (STAUTNER, ERNST W.) 30 September 2010<br>See paragraphs [0020] -[0022] and figure 2. | 1-6 |
| A | JP 2001-077434 A (MITSUBISHI ELECTRIC CORP.) 23 March 2001<br>See paragraphs [0013] , [0014] and figure 1. | 1-6 |
| A | JP 2003-086418 A (MITSUBISHI ELECTRIC CORP.) 20 March 2003<br>See paragraphs [0012] , [0014] and figure 1. | 1-6 |
| A | US 2011-0039707 Al (BURGESS et al.) 17 February 2011<br>See paragraphs [0026] , [0027] and figure 1. | 1-6 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 22 FEBRUARY 2013 (22.02.2013) | **25 FEBRUARY 2013 (25.02.2013)** |
| Name and mailing address of the ISA/KR<br>Facsimile No. 82-42-472-7140 | Authorized officer<br>SUNG, Ho Keun<br>Telephone No. 82-42-481-5580 |

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/KR2012/009912**

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| | | WO 2007-057709 A1 | 24.05.2007 |